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Relationships between wind predictions and model resolution over coastal regions

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ABSTRACT

The impact of resolution on wind predictions within regions of complex coastal geometry is evaluated using a quadruple nest of COAMPS® (27 km to 1 km) to find an optimal configuration of spatial and temporal resolution. Two regions, Turkish Straits System and Chesapeake Bay, are selected because of their diverse coastal environments, the availability of wind observations and to determine if the relationships between resolution and wind prediction accuracy would be valid for geographically different regions. The coarse resolution model successfully simulates the general trend of the surface wind variation, but cannot capture peak events accurately. Increased spatial resolution results in more accurate wind predictions. The coastline representation and land features impact friction over land and blocking of the winds and affect accuracy of wind predictions. 27-km resolution products lack important details over coastal waters and are not adequate to force high resolution ocean models. No evident improvement in accuracy is observed when increasing the resolution from 3-km to 1-km. An increase in frequency of the wind records from 3-hourly to hourly is required to capture frontal events with strong wind speeds and sharp gradients. Our analysis for both regions suggests the use of hourly atmospheric products at 3-km resolution for oceanic forcing purposes.

1. Introduction

Winds can be quite influential on the dynamics in coastal oceans and seas. Thus, modeling the atmospheric dynamics over semi-enclosed basins and in locations where topography and geometry strongly affect the atmospheric flow is important for ocean modeling. Ocean models are generally forced with atmospheric forcing created from atmospheric model predictions. However, most operational atmospheric models produce forecast products that are of coarser spatial resolution with respect to ocean model grids (Radnoti et al., 1995; Hodur, 1997; Michalakes et al., 1998; Majewsky, 1998). The coarse resolution may lead to the omission or misrepresentation of important land features such as valleys, straits, or islands, and may also prevent the atmospheric models from accurately representing the smaller scale dynamics actually present in the atmosphere. Local wind events that largely influence near-coastal ocean circulation are expected to depend on these smaller scale atmospheric dynamics. Advancements in the speed of available computational resources allow oceanographers and coastal engineers to push the limits of applicability of their coastal models by increasing spatial resolution and temporal frequency. This, in turn, enables researchers to simulate more challenging environments, where complex geometries and convoluted coastlines are integral to both the atmospheric and oceanic response in the region. This interplay between atmospheric and oceanic dynamics, resolution, and computational cost emphasizes the importance of finding an optimum resolution in the atmospheric forcing for both computational efficiency and model accuracy.

The spatial resolution and temporal frequency of atmospheric predictions play an important role in the ability of an ocean model to capture pertinent ocean dynamics. Cavaleri and Bertotti (2006) showed that an increase in the resolution of the meteorological model from 188 km to 25 km brought predicted winds closer to the measured data because of an improved description of the coastline and orography bordering the sea, but, the model still underestimated and failed to properly capture the peak winds associated with storm events. Zampato et al. (2007) reported similar results in the Adriatic Sea when the resolution of meteorological fields increased from 25 km to 7 km. At the coarse resolution, relatively smooth winds severely underestimated wind speeds while higher resolution winds reproduced observed wind

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fields with better structure and intensity. The work of Zampato et al. (2007) reinforced that winds are modulated due to orography of the Dinaric Alps over Croatia. Lebeaupin-Brossier et al. (2011) demonstrated that increasing the resolution from 20 km to 6.7 km in the north-west Mediterranean Sea resulted in higher wind stress values, especially near coasts and wind corridors. The use of higher frequency atmospheric forcing (3-h) allowed resolution of the diurnal cycle and resulting intense wind gusts.

Recent studies have investigated the impact of even higher spatial and temporal resolutions on model predictions. Pullen et al. (2003) found that a higher spatial resolution (4-km) atmospheric model produced wind velocity results with smaller RMS errors, but, is not superior to the coarse resolution (36-km) model when correlations are compared at stations in the Adriatic Sea. Signell et al. (2005) assessed the quality of surface winds and their influence on wave prediction in the Adriatic Sea by analyzing four different meteorological models at different spatial resolutions ranging from 40-km to 4-km. Significantly stronger and more accurate wind speeds resulted from the higher resolution atmospheric models. Similar to the findings of Pullen et al. (2003); Signell et al. (2005) demonstrated that the coarse atmospheric model had the best correlation of the winds to observations, a result which was attributed to the fact that the coarse winds are smoother and have less "noise". Dong et al. (2011) studied a synoptic upwelling event in the Southern California Bight and investigated the sensitivity of the ocean model to wind resolution. They compared the atmospheric predictions as resolution increased and concluded that the model results for alongshore wind stress and wind curl approached saturation as resolution increased from 6-km to 2-km.

Specific studies on the effects of wind channeling and gap winds in geometrically and topographically complex regions, such as the Hawaiian islands (Zhang et al., 2005), the Cook Strait region in New Zealand (Reid, 1996), the Shelikof Strait region in Alaska (Lackman and Overland, 1989), and Howe Sound in British Columbia (Jackson and Steyn, 1994), emphasized the importance of enhancing the model grid resolution to accurately capture such events. Grids having resolutions of at least 3-km were shown to resolve complex coastlines and major terrain features that are necessary to capture small-scale events like gap winds in the model solution.

Temporal resolution is as significant as spatial resolution for capturing fast-moving, short-lived events such as storm fronts in atmospheric predictions. Models of high spatial resolution show high frequency variability of wind fields that are characterized by a more detailed, temporally variable structure. Klaic et al. (2011) compared coarse resolution, 6-hrly ECMWF model winds with higher resolution, 3-h ALADIN model winds. The conclusion was that low and high temporal resolution model results were of comparable magnitude, with the latter exhibiting fine structures while the former resulted in more homogeneous wind fields over the entire Adriatic domain.

Some of the earlier studies focusing on the impact of atmospheric forcing on the performance of coastal ocean models (i.e. Signell et al., 2005) have neglected to isolate the effect of spatial resolution alone, since comparisons were made using results from multiple atmospheric models, such as a coarse regional model versus a fine-scale limited-area model where each model had different physics, parameterizations, and numerics in addition to resolution differences. In this study, we investigate the effect of spatial resolution by comparing results from the same atmospheric model, the only differences being the resolution of the computational grid. The computed atmospheric winds are compared to multiple independent in-situ observations collected at meteorological stations around the coast in order to better quantify the predictive skill of the atmospheric model, to evaluate its overall performance, and to potentially identify an optimal resolution for atmospheric predictions.

Even if many studies show the advantage of enhancing spatial resolution, the importance of and the dependence on coastline geometry and orography is region-dependent, and as such, so are the benefits obtained from higher spatial resolution wind fields. Furthermore, increasing the resolution beyond a certain threshold may not always be advantageous considering accuracy (Mass et al., 2002) and also the need for more computational power. Besides, the implied physics contained with the atmospheric model may no longer be applicable beyond a certain level of spatial resolution.

Most earlier studies investigated the impact of atmospheric forcing resolution on oceanic predictions, and most only briefly assessed performance of the atmospheric model itself and the impact of resolution on atmospheric predictions, used to create the atmospheric forcing products. The motivation of this study is to provide a detailed analysis of wind field predictions at varying resolutions to understand the impact of resolution in atmospheric predictions over the coastal ocean. We aim to determine if atmospheric predictions converge as the resolution increases and determine if there is an optimal resolution that maximizes accuracy.

This study examines the impact of spatial and temporal resolution of an atmospheric model's wind field predictions over two coastal regions, each selected for their diversity, complexity, and the availability of wind observations, the Turkish Straits System (TSS) and the coastal area identified by the Chesapeake Bay, MD. Similar atmospheric predictions were used to force the ocean models for both regions (Blain et al., 2009; Blain et al., 2012; Chu et al., 2012). The TSS region has complex shorelines that influence the oceanographic response, while circulation in the region surrounding Chesapeake Bay is significantly influenced by intense daily/weekly frontal passages. The reason for studying multiple regions is to understand if the findings on the impact of resolution on wind predictions are region-dependent or not. Since the coastal ocean dynamics in each region is strongly influenced by atmospheric events, the quality of the atmospheric predictions used as forcing may be considered crucial for obtaining more accurate oceanic predictions.

Initially, we assess the performance and accuracy of an atmospheric model's operational product by comparing its wind predictions to the measurements from meteorological stations. Additionally, triple and quadruple-nested configurations of the atmospheric model are then applied to evaluate the impact of increasing spatial resolution. Model-data comparisons not only consider bulk statistics, but, also examine details, such as the coastline representation of each modeling system, in order to better understand the reasons for change in the wind predictions over coastal waters. We also investigate the impact of using high spatial resolution winds at higher frequencies to quantify the impact and importance of temporal resolution over coastal waters.

Descriptions of the atmospheric model and its configuration, as applied, along with details of application areas are presented in Section 2. Section 3 addresses the effect of spatial and temporal resolution for application over the Turkish Straits System followed by an analysis over the Chesapeake Bay region. The final section summarizes the findings and provides conclusions.

2. Model configuration and observations

2.1. Numerical model description

In this study, the atmospheric model component of the Coupled Ocean Atmosphere Mesoscale Prediction System (COAMPS®) is used alone. COAMPS® is a three-dimensional data assimilative